



NASA SBIR 2022 Phase I Solicitation

S16.05 Thermal Control Systems

Lead Center: GSFC

Participating Center(s): JPL, JSC, LaRC, MSFC

Scope Title

Coatings for Lunar Regolith Dust Mitigation for Thermal Radiators and Extreme Environments

Scope Description

Thermal coatings are an integral part of a space mission and are essential to the survivability of the spacecraft and instrument. Radiator surface coatings with desired emissivity and absorptivity provide a passive means for instrument temperature control. The utilization of variable-emittance devices further enables active control of the instrument temperature when the heat output from the instrument or the thermal environment of the radiator changes. With NASA's new initiative to return to the Moon, a new coating technology that will keep surfaces clean and sanitary is needed. New coating formulations utilizing durable, anticontamination, and self-cleaning properties that will disallow the accumulation of dust, dirt, and foreign materials are highly desirable. These coatings can have low absorptance and high infrared (IR) emittance properties or be transparent for use on existing thermal coating systems. The goal of this technology is to preserve optimal long-term performance of spacecraft and habitation components and systems. Furthermore, coatings that can survive and operate in extreme environments (cryogenic or high temperature) are desirable.

Expected TRL or TRL Range at completion of the Project

2 to 5

Primary Technology Taxonomy

Level 1

TX 14 Thermal Management Systems

Level 2

TX 14.3 Thermal Protection Components and Systems

Desired Deliverables of Phase I and Phase II

- Analysis

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- Prototype
 - Hardware

Desired Deliverables Description

Phase I Deliverables:

- Successful development of coating formulations that lead to the desired dust mitigation.
- Deliverable of coupon.
- Samples of the hardware for further testing at NASA facilities.
- Final report.

Phase II Deliverables:

- Results of performance characterization tests.
- Results of stability test of the coating formulations and their mechanical durability test under the influence of simulated space and lunar environmental conditions.
- Test coupon.
- Final report.

State of the Art and Critical Gaps

There are limited options for durable, stable thermal control coatings that are dust shedding in charging environments. Current state-of-the-art, sprayable radiation-stable coatings are able to coat complex, irregular surfaces, but they are porous and will become imbedded with dust and particulates. Other surface films tend to be less optically stable and may charge in the plasma environment, thereby attracting lunar regolith to their surfaces. Mirrors have the limitations of requiring flat surfaces and are not conformal in nature. Currently, no single thermal control surface appears to provide stability, durability, and meet optical property requirements for sustained durations in space and lunar environments.

Relevance / Science Traceability

Many Sciences Mission Directorate (SMD) missions will greatly benefit from this dust mitigation thermal coating technology: any lunar-related project and projects involved with robotic science rovers and landers.

References

- References for dust mitigation coatings such as lotus thermal coatings: <https://ntrs.nasa.gov/search.jsp?R=20150020486>
- References for extreme environment coatings: https://vmf.jpl.nasa.gov/files/EE-Report_FINAL.pdf
- References in Subtopic Z13.01, Active and Passive Dust Mitigation Surfaces.

Scope Title

Heat Pumps for High-Temperature Sink Environments

Scope Description

Operations in extreme environments where the environment sink temperature exceeds spacecraft hardware limits will require active cooling if long-duration survivability is expected. Robotic science rovers operating on the lunar surface over diurnal cycles face extreme temperature environments. Landers with clear views of the sky can often achieve sufficient heat rejection with a zenith or, if sufficiently far from the equator, an anti-Sun-facing radiator. However, science rovers must accommodate random orientations with respect to the surface and Sun. Terrain features can then result in hot environment sink temperatures beyond operating limits, even with shielded and articulated radiator assemblies. Lunar dust degradation on radiator thermo-optical properties can also significantly affect effective sink temperatures. During the lunar night, heat rejection paths must be turned off to preclude

excessive battery mass or be properly routed to reclaim nuclear-based waste heat.

Science needs may drive rovers to extreme terrains where steady heat rejection is not otherwise possible. The paradigm of swarms or multiple smaller rovers enabled by commercial lander opportunities will need to leverage standard rover bus designs to permit flexibility. A heat pump provides the common extensibility for thermal control over the lunar diurnal. Active cooling systems or heat pumps are commonly used on spacecraft. Devices used include mechanical cryocoolers and thermoelectric coolers. For higher loads, vapor compression systems have been flown, and more recently, reverse turbo-Brayton-cycle coolers are being developed under NASA's Game Changing program for high-load, high-temperature-lift cryocoolers. However, technology gaps exist for midrange heat pumps that are suitable for small science rovers where internal heat dissipation may range from 20 to 100 W.

Expected TRL or TRL Range at completion of the Project

2 to 5

Primary Technology Taxonomy

Level 1

TX 14 Thermal Management Systems

Level 2

TX 14.X Other Thermal Management Systems

Desired Deliverables of Phase I and Phase II

- Research
- Analysis
- Prototype

Desired Deliverables Description

- Conceptual design (Phase I).
- Physics-based analysis or model (Phase I).
- Proof-of-concept hardware (Phase I).
- Proof-of-concept hardware tested against simulated loads in proposed environments (Phase II).
- Final report (Phase I, Phase II).

State of the Art and Critical Gaps

Specifically, heat pump systems are needed with the following:

- Temperature lift from a cold side at $<50\text{ }^{\circ}\text{C}$ to an environmental sink temperature as high as $75\text{ }^{\circ}\text{C}$ (temperature lift of $50\text{ }^{\circ}\text{C}$ or heat rejection rate of 230 W/m^2), with a system coefficient of performance >2.5 .
- Tolerance to being powered down during the lunar night and restarted during the day reliably over multiple diurnals.
- Minimal exported vibrations, if any, for compatibility with science instruments.

Novel heat-pump systems are desired. Enabling improvements to state-of-the-art systems are also welcome.

Relevance / Science Traceability

NASA's lunar initiative and Planetary Science Division form the primary customer base for this technology. Missions that directly address the National Research Council Planetary Science Decadal Survey may be users of

this technology.

References

- Apollo Lunar Roving Vehicle Documentation: <https://www.hq.nasa.gov/alsj/alsj-LRVdocs.html>
- Apollo Experience Reportâ€”Thermal Design of Apollo Lunar Surface Experiments Package: <https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19720013192.pdf>
- Thermal Considerations for Designing the Next Lunar Lander: <https://aip.scitation.org/doi/10.1063/1.2437438>

Scope Title

Advanced Manufacturing of Loop Heat Pipe Evaporator

Scope Description

A loop heat pipe (LHP) is a very versatile heat transport device that has been used on many spacecrafts. At the heart of the LHP is the evaporator and reservoir assembly. During the manufacturing, tedious processes are required to machine the porous primary wick and insert it into the evaporator, and both ends of the wick need to be sealed for liquid and vapor separation. One commonly used method for vapor seal is to use a bimetallic knife-edge joint, which is more prone to failure over long-term exposure to thermal cycles and shock and vibration. These tedious manufacturing processes add to the cost of the traditional LHP. A new manufacturing technique that will allow the primary wick to be welded directly to the reservoir without the use of a knife-edge seal is needed in order to reduce the cost and enhance the reliability.

Expected TRL or TRL Range at completion of the Project

4 to 6

Primary Technology Taxonomy

Level 1

TX 14 Thermal Management Systems

Level 2

TX 14.X Other Thermal Management Systems

Desired Deliverables of Phase I and Phase II

- Analysis
- Prototype
- Hardware

Desired Deliverables Description

- Successfully develop advanced techniques to manufacture the LHP evaporator and reservoir assembly (Phase I).
- Demonstrate the performance of the evaporator/reservoir performance in an LHP setup (Phase I).
- Demonstrate the performance of the evaporator/reservoir performance in an LHP setup optimized to operate in simulated realistic environments with appropriate cycling (Phase II).
- Final report (Phase I, Phase II).

State of the Art and Critical Gaps

The LHP evaporator contains a porous wick, which provides the capillary pumping capability to sustain the fluid flow in the loop. The smaller the pore size of the wick, the higher its capillary pumping capability. However, a smaller pore size results in a higher flow resistance that must be overcome by the capillary force. Traditional sintered metal wicks have a pore size on the order of 1 μm and porosity around 0.4 to 0.6. In order to replace the traditional porous wick, the new wick produced by the advanced manufacturing technology must have comparable pore size and porosity. The smallest pore size currently produced by direct metal laser sintering is on the order of 10 μm .

Relevance / Science Traceability

Traditional LHPs are used on many NASA missions including the Ice, Cloud, and Land Elevation Satellite (ICESat), ICESat-2, Swift, Aura, Geostationary Operational Environmental Satellite (GOES), Geostationary Operational Environmental Satellite-R Series (GOES-R), and Surface Water and Ocean Topography (SWOT). Similar future Science Mission Directorate (SMD) missions, especially those using small satellites, can greatly benefit from this technology.

References

Richard, Bradley, et al.: "Loop Heat Pipe Wick Fabrication via Additive Manufacturing," NASA Thermal & Fluid Analysis Workshop, August 21-25, 2017, Marshall Space Flight Center, Huntsville, AL.

Scope Title

Approaches and Techniques for Lunar Surface Payload Survival

Scope Description

The lunar environment poses significant challenges to small, low-power (~100 W or less) payloads, rovers, and landers required for lunar science. The lunar day/night cycle is approximately one Earth month. During that time, surface temperatures on the lunar surface can reach 400 K at local solar noon or drop to below 100 K during the lunar night—and even colder in permanently shadowed regions. These hot and cold conditions can last several Earth days, because of the slow rotation of the Moon, or permanently in shadowed craters. Lunar dust deposited on heat-rejection surfaces and coatings will increase the heat absorbed from the Sun, thus reducing the effectiveness of radiators for heat rejection. The lunar gravity, which is 1/6th of the Earth's, will limit the ability of typical low-power heat transport devices, but the gravity field may provide advantages that could be utilized. Higher heat dissipation capacity should be addressed in Z2.01. This call seeks to solicit innovative proposals to enable lunar science in the difficult lunar environment. Example technologies may include, but are not limited to, active loops that may be turned off and are freeze tolerant, zero- or low-power nonconsumable/regenerative heat generation sources, high-thermal-capacitance thermal storage, advanced insulation, and passive switching with high turndown ratios (e.g., >400:1). Furthermore, small form factors are also desired. Technologies should show substantial increase over the state of the art. Technology proposals should address power usage in day and night/shadow, mass, heat transport when turned on, heat leak when turned off, temperature drops through the system, heat storage/release amount, sensitivity to lunar topography and orientation, and so forth.

Expected TRL or TRL Range at completion of the Project

3 to 4

Primary Technology Taxonomy

Level 1

TX 14 Thermal Management Systems

Level 2

TX 14.2 Thermal Control Components and Systems

Desired Deliverables of Phase I and Phase II

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- Analysis
 - Prototype
 - Hardware

Desired Deliverables Description

Thermal management approaches, techniques, and hardware components to enable the accommodation of temperature extremes encountered in the lunar environment. Concept model deliverable for Phase I and prototype demonstration in relevant environment in Phase II.

State of the Art and Critical Gaps

Missions like Surveyor and Lunokhod hibernated during the night or reduced operational power near noon, in attempts to survive single or multiple lunar cycles. ALSEPs (Apollo Lunar Surface Experiments Packages) were deployed on several Apollo missions and had select experiments that operated for many lunar cycles. However, both Lunokhod and ALSEP benefited from radioisotope heat and power sources, which are either too expensive or not likely to be available for near-term future lunar science experiments. In fact, most modern lunar surface mission planning is based on solar power and batteries and typically avoids the challenges associated with surviving the full lunar cycle or shadowed regions. Because interest in lunar science and the development of abilities to deliver payloads to the lunar surface is resurgent, the capability to operate through the entire lunar environment is critical. In the absence of perpetual power supplies like radioisotope thermoelectric generators (RTGs), thermal management approaches to accommodate the lunar extremes, extended day/night cycles, and shadowed regions are seen as enabling.

Relevance / Science Traceability

Science Mission Directorate (SMD) lunar surface science investigations will employ small, low-power payloads that will require advanced thermal control approaches and techniques to survive and operate for extended duration through extreme thermal environments on the lunar surface.

NASA has plans to purchase services for delivery of payloads to the Moon through the Commercial Lunar Payload Services (CLPS) contract. Under this subtopic, proposals may include efforts to develop payloads for flight demonstration of relevant technologies in the lunar environment. The CLPS payload accommodations will vary depending on the particular service provider and mission characteristics. Additional information on the CLPS program and providers can be found at this link: <https://www.nasa.gov/content/commercial-lunar-payload-services>. CLPS missions will typically carry multiple payloads for multiple customers. Smaller, simpler, and more self-sufficient payloads are more easily accommodated and would be more likely to be considered for a NASA-sponsored flight opportunity. Commercial payload delivery services may begin as early as 2021, and flight opportunities are expected to continue well into the future. In future years it is expected that larger and more complex payloads will be accommodated. Selection for award under this solicitation will not guarantee selection for a lunar flight opportunity.

References

- NASA Prepares for Performing New Science on the Moon: <https://www.jpl.nasa.gov/news/news.php?release=2007-068>
- The Surveyor Program: <https://history.nasa.gov/TM-3487/ch2-1.htm>
- The Surveyor Program: [https://www.lpi.usra.edu/lunar/missions/surveyor/\(link is external\)](https://www.lpi.usra.edu/lunar/missions/surveyor/(link%20is%20external))
- Missions - Lunokhod 01: <https://solarsystem.nasa.gov/missions/lunokhod-01/in-depth/>
- Missions - Lunokhod 02: <https://solarsystem.nasa.gov/missions/lunokhod-02/in-depth/>